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ANALYSIS OF CHANGES IN DRIVER REACTION TO IMPROVED WARNING DEVICES AT A RURAL GRADE CROSSING

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INDIANA STATE HIGHWAY COMMISSION

Technical Paper

ANALYSIS OF CHANGES IN DRIVER REACTION TO IMPROVED WARNING DEVICES AT A RURAL GRADE CROSSING

TO: J. F. McLaughlin, Director
Joint Highway Research Project

January 13, 1976

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FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-59N

Attached is a Technical Paper titled "Analysis of Changes in Driver Reaction to Improved Warning Devices at a Rural Grade Crossing". The paper is authored by Messrs. E. R. Russell, H. L. Michael and T. A. Butcher, all participants in the HPR Research Study from which the paper has been prepared. The Final Report on this HPR Study titled "A Field Evaluation of Driver Information Systems for Highway-Railroad Grade Crossings" has been accepted by all sponsoring organizations.

The paper will be presented at the Annual Meeting of the Transportation Research Board in Washington, D.C. in January 1976. It may be published by that organization and approval of such publication is requested. Copies of the Paper will be forwarded to ISHC and FHWA for information. The Final Report has been accepted and approval of the Paper is not required from FHWA.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
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HLM:ms

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16. Abstract

The objectives of this research were to analyze the effect on motorists of improving the warning devices at a high-accident, rural grade crossing, from 8-inch flashers to automatic gates and 12-inch flashers activated by a Marquardt speed predictor and having additional strobe lights; to evaluate suitable parameters and to make the analysis; to study accident history and site conditions and relate these to motorist reaction to the system - before and after; and to evaluate the data collection system itself.

Spot speeds were taken at eight points on each approach to obtain an approach speed profile for various groups under various conditions after the signal system was improved. These were compared to similar data taken before system improvement.

It was shown that an activated gate arm can be as effective in slowing the average approaching vehicle as a train across the road. The strobe lights made the warning system more visible after activation.

Most drivers approach a grade crossing safely and mean speed of various groups shows trends but is a relatively weak parameter to test effectiveness, because they do not isolate the occasional, unsafe driver. Percent reduction of fastest cars, along with examining individual "fastest" cars, is a better parameter than mean speeds and deceleration to show improved effectiveness.

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INTRODUCTION

In early 1972, the Indiana State Highway Commission sought an immediate solution to a grade-crossing problem where pressure by the press and local citizens was mounting because of a high accident and death record. This location was the crossing of U.S. 31, a four-lane, 65 mph (posted) highway, and Norfolk and Western (N & W) tracks near Goldsmith, Indiana. A three phase research proposal was initally prepared:

1. Install traffic signal type overhead red flashers on cantilever arms over the highway at the crossing, activated with the standard railroad flashers.

2. Install an overhead luminaire to illuminate the crossing during passage of a train, activated concurrently with the overhead flashers.

3. Install automatic gates.

The primary purpose of the research was to determine quantitatively the degree of effectiveness of each of the planned improvements. This included the development of simple techniques capable of measuring parameters whose characteristics were found to be related to the degree or quality of improvement.

Spot speed at specific points on the approaches was selected as the parameter most likely to be related to the degree of improvement. Such speeds taken at several points of approaching drivers provided an "approach-speed profile" for each driver. Inferences from the evaluation of these approach-speed profiles and changes in them due to each improvement or to change of conditions within a particular system, were used to evaluate the effectiveness of the improvements.

The before (Phase 1) data was obtained during the Spring of 1972. However, the original concept of a 3-phase improvement program had to be scrapped due to inability to negotiate necessary State-Railroad agreements for the total research project. Only one improvement, an automatic gate system with strobe lights on the gate arms, was installed at the grade crossing in April of 1973. The primary purpose of the research then became the analysis of the effect of this automatic gate system and driver reaction to it and other site conditions.

After the gates were installed, a three week delay was allowed for local drivers to become accustomed to the new system. Data collection for the after condition (Phase II) then commenced. At the end of data collection for Phase II, an analysis was made of the complete, combined before and after data sets.

OBJECTIVES

As carried out, the specific objectives of the research at the Goldsmith grade crossing were as follows:

1. To determine the effectivess of the automatic gate system by an analysis of the before and after approach speed profiles and related parameters.

2. To evaluate speed and related parameters (such as, deceleration rates, above pace speeds, highest speeds, speed distributions, etc.) as sensitive measures of significant change in effectiveness.

3. To evaluate site conditions and accident history associated with this crossing as they relate to driver approach speeds and characteristics.

4. To evaluate the effectivess of the selected filming system for data collection.

ORIENTATION OF THE GOLDSMITH CROSSING

The crossing is located approximately one mile north of the intersection of U.S. 31 and State Road 28, which is controlled by a traffic signal. U.S. 31 is a four-lane divided highway, with north-south orientation over level terrain. Lane widths are twelve feet and the median is 66 feet in width. Posted speed was 65 miles per hour, and the 85th and 15th percentile speeds were 66 and 50 mph, respectively.* The highway ADT is approximately 10,000 vehicles.

The railroad track is a single main line track oriented at 90° with the highway, in an east-west direction. There are about six freight trains operated on an "as needed" basis (no set schedule) with a speed range from 20 to 60 miles per hour. The track is level and on tangent for at least a mile in each direction from the highway and elevated above the surrounding fields each side of the crossing.

County Road 100 S parallels the rail tracks on their south side. It is gravel surfaced and carries very light volumes. Its intersection with U.S. 31 is controlled by stop signs with yield signs in the crossover of the median. Separate railroad flashers are directed toward traffic entering U.S. 31 from this road. The layout is shown in Figure 1.

Sight distance along the railroad track for approaching motorists is relatively unobstructed in three quadrants. In the southwest quadrant sight distance of a train is restricted to about 200 feet for northbound motorists because of a woods. For such a northbound motorist, an eastbound train is not clearly visible at the time the signals are activated. When the crop in the southeast quadrant is corn, an obstruction to sight distance could also exist there for a portion of the year. In the northwest quadrant, the field is depressed enough below the road and track that

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*at the time of the study

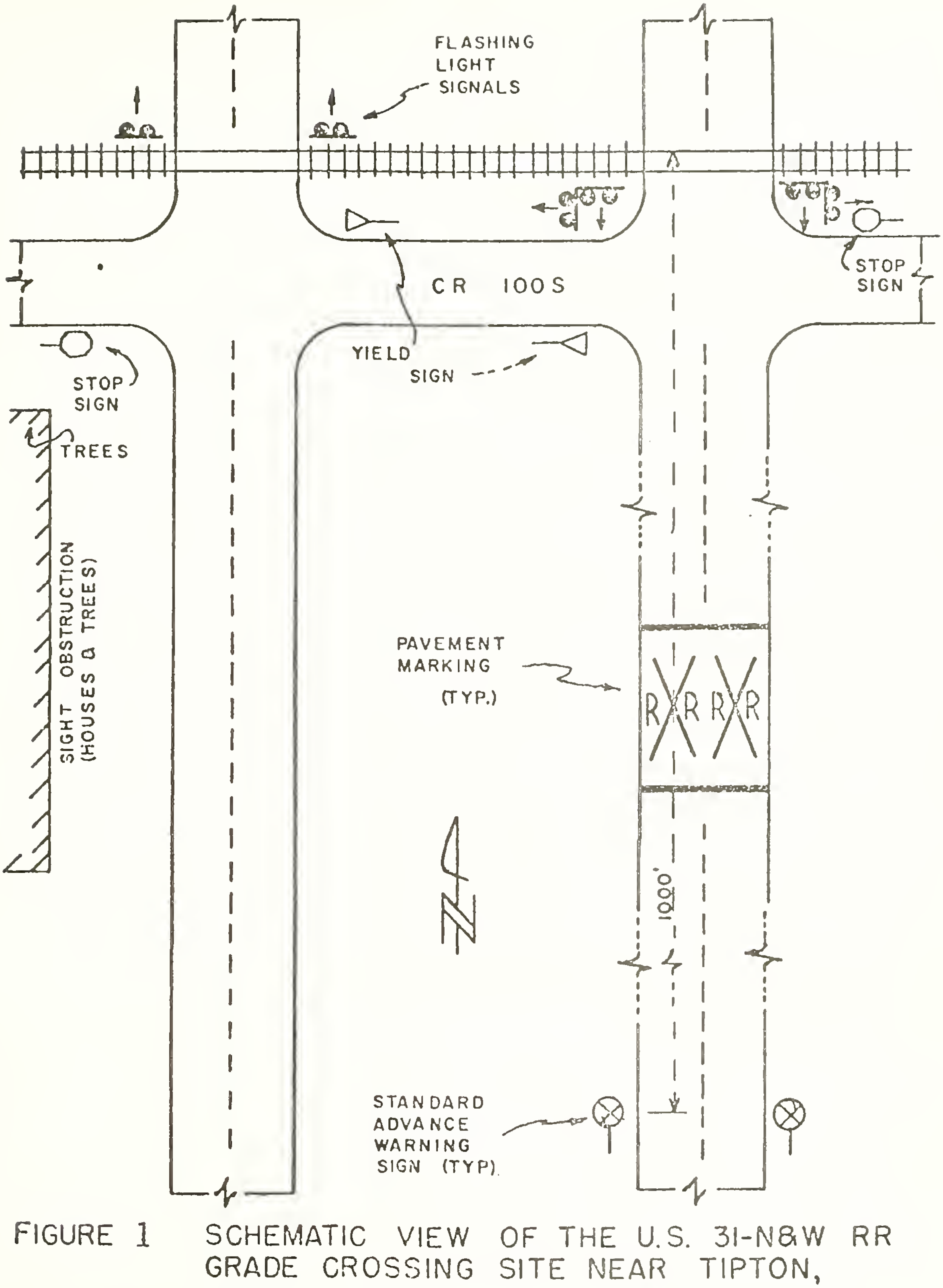

FIGURE 1 SCHEMATIC VIEW OF THE U.S. 31-N&W RR GRADE CROSSING SITE NEAR TIPTON, INDIANA (BEFORE IMPROVEMENT) (REF. 3 , p. 56)

sight distance over crops is unobstructed. However, the wooded area south of and parallel to the track west of the highway presents for southbound traffic a poor background, i.e., a dark train against the dark background creates little contrast and may have the effect of camouflaging a train.

ACCIDENT RECORD

In spite of all the apparent safe features of the site, such as, level terrain, good sight distance, active protection, no-skew, no curved alignment, etc., the accident record here had been (prior to improvement) one of the worst in the State of Indiana, particularly in the prior few years. There had been a total of 38 accidents in 15 1/2 years, including 8 fatal accidents and 14 personal injury accidents which resulted in 13 deaths (all since March 1965) and 26 injuries. Also, almost all of the 38 total accidents at this crossing had occurred during daylight hours with clear skies and dry pavements. Eight of twelve train-involved accidents occurred on the southbound approach where a motorist approaching the crossing has unobstructed sight distance down the track to the west of 1/2 mile or more during the entire last 1/2 mile of his approach to the crossing, and almost as much to the east.

THE DATA COLLECTION SYSTEM

The data necessary to determine driver reaction were spot speeds at sufficient locations to develop a speed profile as a vehicle approached the grade crossing. With these data, the vehicle's rate of deceleration could be calculated and analyzed, and the locations where the driver made noticeable speed changes could be determined.

Time and budget constraints led to the implementation of a photographic system employing a 16 mm variable speed movie camera that could be rented locally.

A camera setup position was determined for each approach approximately 750 feet from the roadway and 600 feet from the railway track. Markers were placed in pairs, parallel to the highway, such that each pair intersected the line of sight from the camera to a 55 foot speed "trap". By filming a vehicle at a set film speed, and counting the frames of the developed film that it took a vehicle to traverse a pair of markers, frame counts were converted to the average speed of the vehicle between marker pairs. This average speed of a vehicle over a 55-foot trap length was assumed to be the vehicle's spot speed at the center of the trap. The photographing setup is shown in Figure 2.

Table 1 lists the eight station designations and their distance from the nearest track to the center of trap, the point at which the spot speed was measured.

Markers were painted white on the side facing the camera and green on the side facing the highway to make them as inconspicuous as possible to passing motorists, and as visible as possible on the film. The camera setup position was far enough from the roadway such that no camouflage was necessary for the camera and observer.

The camera was a 16 mm Ariflex-M motion picture camera equipped with a 12-120 mm Augeneux zoom lens. The camera was driven by an eight-volt variable-speed electric motor and equipped with a tachometer calibrated in frames per second. An initial check on film speed, made by photographing a stop watch, indicated that the tachometer was accurate.

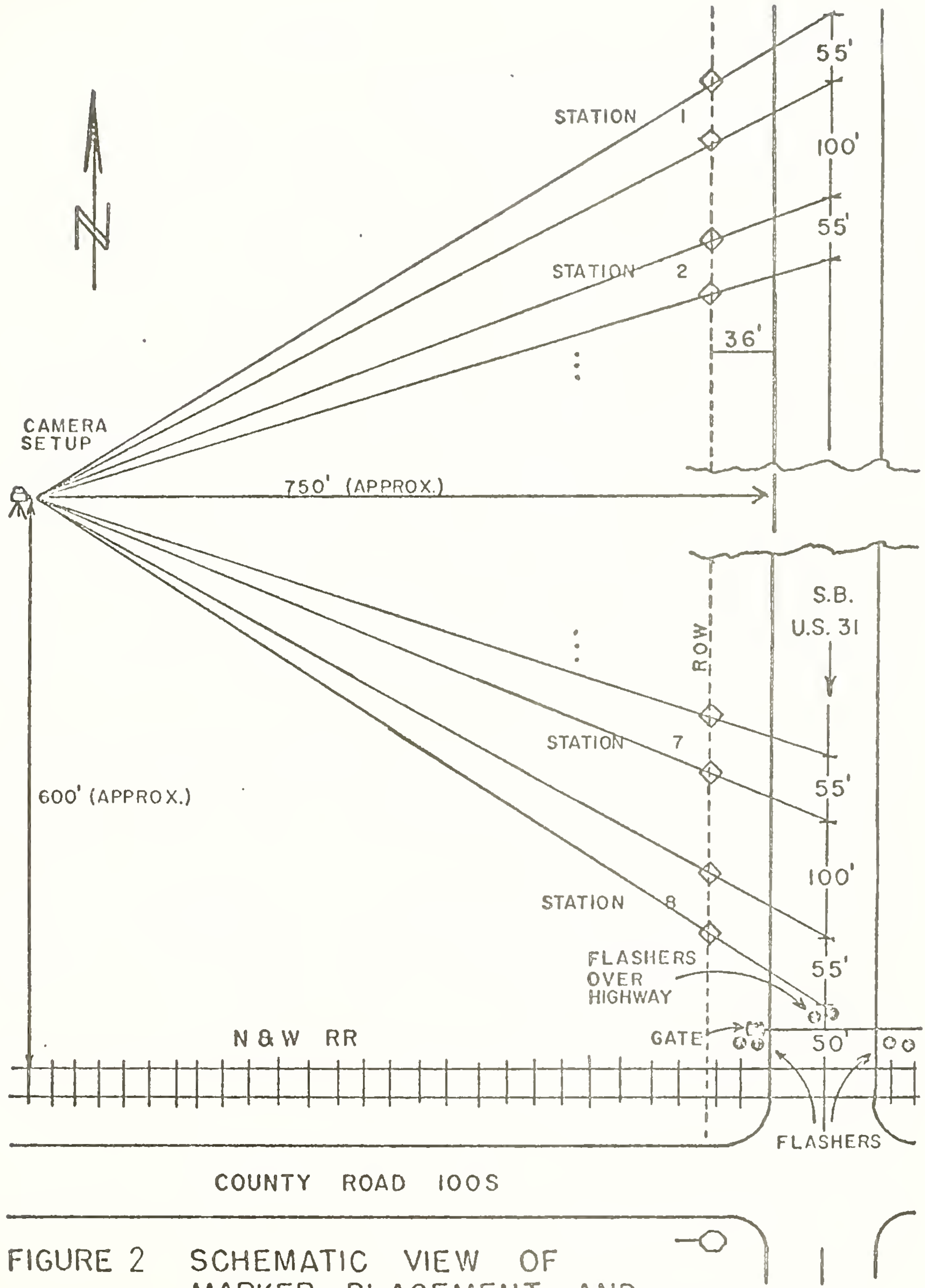

FIGURE 2 SCHEMATIC VIEW OF MARKER PLACEMENT AND CAMERA SETUP POSITION (REF. 29 p. 67)

TABLE 1. NUMBERS AND LOCATIONS OF THE EIGHT SPOT SPEED STATIONS ON EACH APPROACH.

Station Number	Distance from Nearest Track to Center of Trap (feet)
1	1162.5
2	1007.5
3	852.5
4	697.5
5	542.5
6	387.5
7	232.5
8	77.5

ANALYSIS OF PHASE I DATA

General

All data were collected during daylight hours under conditions of clear visibility. In the experimental design, it was decided to place all vehicles into four basic categories: 1) "free flow vehicles," 2) "first unobstructed vehicles," 3) "first obstructed vehicles," and 4) "following vehicles." These categories are defined below:

> A "free flow vehicle" is defined as one in which the motorist travelled through the approach with no train present and no other vehicle between him and the crossing. In this condition there was no stimulus other than the existence of the crossing itself and its unactivated devices.

> A "first unobstructed vehicle" is defined as one driven by the motorist who entered the first speed trap while the signals were flashing but chose to go through the crossing without stopping, ahead of the train, which was not yet near crossing.* The added stimulus was that of the activated flashers and possibly sighting of the approaching train.

> A "first obstructed vehicle" is defined as one in which the motorist entered the first speed trap with the flashers activated and a train already across, or about to cross, the highway. The added stimulus in this case was the train across or very close to the highway.*

> A "following vehicle" is defined as one in which the motorist entered the first speed trap under conditions of signal activation, a train across the highway and at least one other vehicle already stopped at the crossing. The added stimulus in this case was the stopped vehicle(s) on the highway.

The primary method of comparison of drivers' performances during Phase I was to make statistical tests on the differences between mean entry speeds in the first trap for all categories of vehicles on each approach. In particular, tests were made for significant differences of the mean and variances of: 1) free flow car vs. first unobstructed car, 2) free flow car vs. first obstructed car, 3) free flow car vs. following

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*In a few cases, the difference between "first unobstructed" and "first obstructed" vehicle was the observer's judgment as to whether an approaching train was near enough to be perceived as a hazard.

car, 4) first unobstructed car vs. first obstructed car, 5) first unobstructed car vs. following car and 6) first obstructed car vs. following car.

Speeds at the other traps for each category were also plotted, and compared as a percentage of entry speed for each group. These speed profiles were studied as a measure of driver reaction to the crossing protection system.

Deceleration rates were also calculated for each vehicle between each of the eight speed traps assuming constant rate between each pair of spot speeds.

Approach Speeds - Before

Analysis of the before data showed that motorists approaching this crossing reacted differently depending upon the prevailing conditions (stimuli) at the crossing.

First unobstructed vehicles which entered the approach when the signals were activated without a train immediately present entered the approach at the same speed as "free-flow" vehicles and did not begin slowing until relatively close to the crossing. First obstructed vehicles which entered the approach with the added stimulus of a train across, or about to cross, the road slowed earlier and decelerated more gradually. Following vehicles which entered the approach behind vehicles which were already stopped ahead, entered even more slowly. Thus, earlier deceleration of approaching motorists appeared to be a direct funtion of the amount of added stimuli present. Each of the added stimuli at the crossing carried with it a corresponding earlier and more gradual deceleration by the

affected motorists. It was hypothesized that the generally-accepted, superior effectiveness of automatic gates was due to the added stimulus of the gates across the highway, perhaps simulating, to the approaching driver, a vehicle stopped in the roadway.

Deceleration Rates - Before

An analysis of 3640 vehicle deceleration rates, seven for each vehicle, showed that only 20 of them, contributed by 13 vehicles, were higher than the comfortable range as defined by the Traffic Engineering Handbook (1)* These higher rates of deceleration occurred in free flow cars, first unobstructed cars and first obstructed cars and all occurred between 700 and 230 feet of the crossing. Two probable causes are: 1) extremely high approach speed or 2) not becoming immediately aware of the existence of the crossing or approaching train. Whatever the cause, these 13 drivers formed the group with the most potential of being involved in a grade crossing accident; however, it was found that the deceleration characteristics could not be distinguished by groups, i.e., the highest rates were distributed among all groups. Thus, the implication is that the approaching drivers with the greatest accident potential were singularly unattentive or distracted.

DATA COLLECTION PHASE II

The automatic gates were installed at the Goldsmith grade crossing in April 1973. After a three-week period to allow local drivers to adjust to the new system, Phase II, the "after" phase of the research project was begun. Care was taken to reproduce data collection procedures and techniques that had been used during Phase I. The same equipment

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* Numbers in parenthesis refer to the references at the end.

set up and procedures were used. Data Collection for Phase II was carried out and completed during the summer of 1973.

Categories

Previously defined were the categories into which the before data had been grouped; namely, free-flow, first unobstructed, first obstructed and following cars. By definition, a first unobstructed car was one that entered and approached the system, passing through while the signals were flashing but while the train was far enough away to not put the driver in any real danger (subjective judgment of observer). With the gate system, the gates of this installation started down immediately when the signals were activated. Thus, a first car entering Trap 1, 1162 feet from the track had no chance to beat the gate, i.e., during Phase II first drivers entering the speed trap system after activation were obstructed by the gate across the road, so there was no unobstructed category after improvement.

The two "after" categories that were compared to the before data were "first obstructed - after" and following" cars. In regard to the "first obstructed" groups, in the before case the train itself was the initial obstruction and in the after case a gate arm was the initial obstruction.

THE CROSSING PROTECTION - BEFORE

The crossing was protected by two sets of flashing light signals for each approach with 8-inch diameter lens and reflectorized crossbucks. There was an additional set of flashing lights aimed down each approach of County Road 100 S. Times of signal activation before the train reached the crossing varied greatly with times up to 90 seconds observed from some particularly slow moving trains.

Standard advance warning signs were placed in pairs, one on each side of the road of each approach, at a distance of 1000 feet from the tracks. As a temporary countermeasure to public pressure to improve protection at the crossing, one battery operated, portable yellow flasher of the construction barricade type had been attached to each advance warning sign. They were small and dim and flashed continuously. In daylight they were hardly noticeable. These remained in place throughout the collection of phase I data. There was no reasonable way to measure their effect which was assumed to be negligible.

Standard pavement markings were painted across both lanes of each approach. All signs, signals, and markings were well maintained and in good order.

THE CROSSING PROTECTION - AFTER

The upgraded Goldsmith protection system consisted primarily of automatic gates with full width gate-arms. The gates across the southbound lanes were designed and placed to block three lanes, that is, the two existing lanes plus a future left-turn lane to the county road planned by the State Highway Commission. These were supplemented by several pairs of flashing lights. On the southbound approach there was one pair on each side of the roadway as well as one pair over each lane on a tubular, cantilever structure. On the northbound approach there were only two pair, one over each roadway. In addition there was one pair of flashing lights aimed toward each approach of C. R. 100 S. All flashers are larger (12-inch lenses) and had a higher light intensity than the ones that had been in place originally.

The gate arms have the standard, lantern-type red lights on each arm. In addition, six strobe lights were installed on each arm. The strobe lights have red lenses aimed toward each approach and are activated concurrently with the standard flashers and flash independently of each other.

New reflectorized advance warning signs were placed on each approach, in place of the original ones. No yellow flasher was used with the new signs. Standard pavement markings were in place as before.

This active system, (gates, flashers, arm lanterns and strobes,) is all activated by a Marquardt speed predictor. The Marquardt system activates the signals at this crossing such that all trains are 25 seconds away from the crossing regardless of speed. Although there is usually an approximate 10 second delay after signal activation prior to gate descent, the gates at this crossing start to descend immediately and are completely down within 10 seconds.

METHOD OF COMPARISION OF AFTER VS. BEFORE DATA

The speed data taken before the gates had been installed, the "before" data, were recoded to conform to the coding of the "after" data and incorporated to form into one data set. Thus, comparisons within the before subset could be reproduced as well as any others that might be of interest.

The primary method of analyzing data within the Phase I subset had been by comparing entry speeds, approach speed profiles and deceleration rates. Some refinements were made when analyzing the Phase II data.

Deceleration rates were calculated and recorded along with all appropriate speed data. Thus, for all "mean values at speed-trap locations" reported, all corresponding "between trap mean decelerations" are also included.

The second refinement was that a t-test of the means was performed on a trap by trap basis to determine significant differences between selected pairs of mean speeds at each of the eight traps as well as each of the seven deceleration zones between traps. Previously, t-tests had only been run on entry speed pairs.

Mean deceleration rates are of such a low magnitude that they are concluded to be a relatively meaningless parameter. However, showing the deceleration rates in the tables* does make trends in the speed profile more clear. (4)

THE AFTER VS. BEFORE COMPARISONS

Free-Flow Speed Profile Comparisons

The results of the analysis of free-flow vehicles are presented in Figures 3 and 4. Two points are obvious from the plots of the approach speeds of all classes of vehicles. First, there is a decrease in "after" speed, relative to before speed, at all traps along each profile except that the entry speed for nothbound cars was about the same. Secondly, before and after speed profiles for their respective groups are essentially parallel. These two factors indicate that motorist responses to both the old and new system were similar but at slightly reduced speed throught their approach for the after condition. Comparing northbound and southbound speed profiles showed slightly higher speeds in all categories of southbound vehicles both before and after.

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* Refer to original report for tables which are to numerous and lengthy to include herein (4).

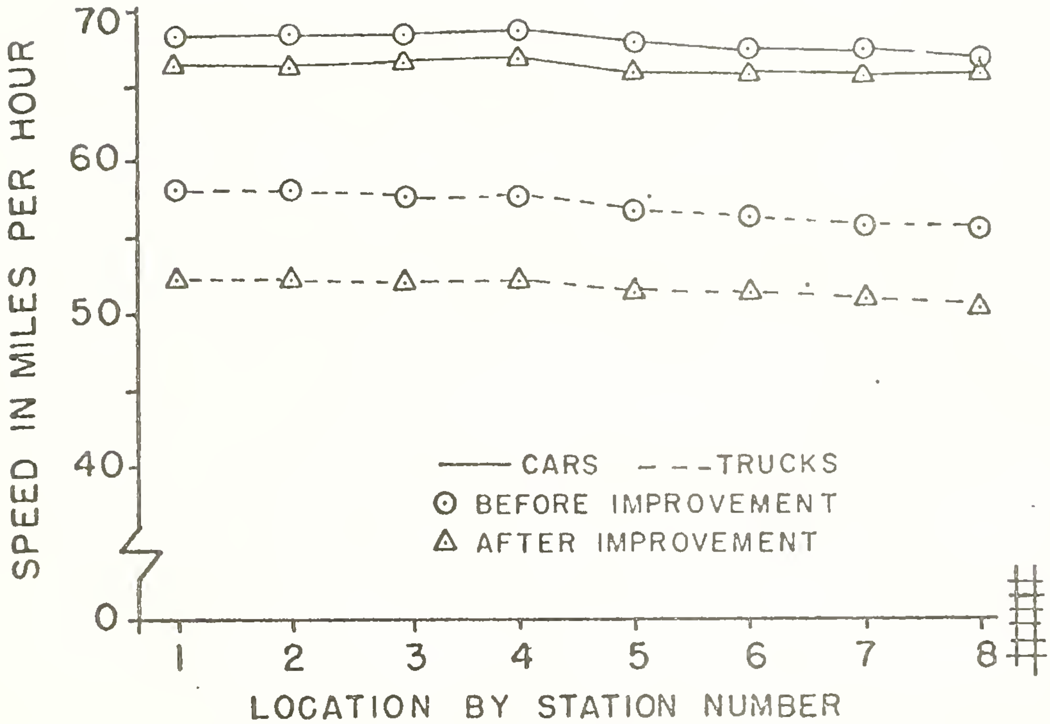

FIGURE 3 SPEED LOCATION GRAPH FOR SOUTHBOUND FREE-FLOW CARS

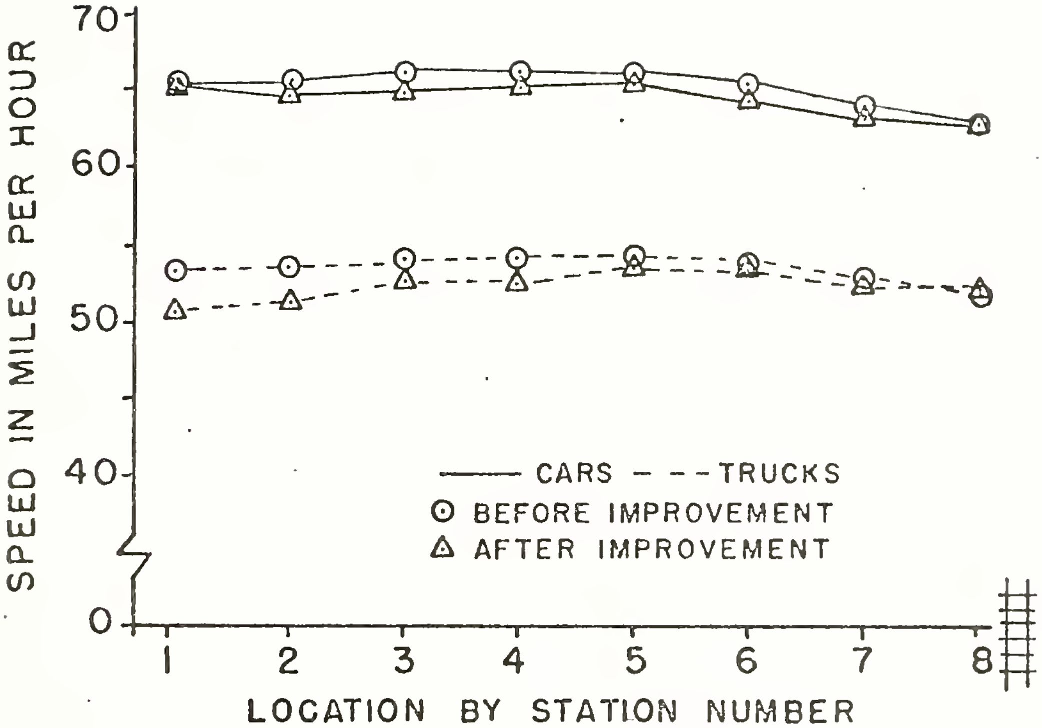

FIGURE 4 SPEED LOCATION GRAPH FOR NORTHBOUND FREE-FLOW CARS

On the northbound approach, comparing before and after, the entry speeds of cars were the same but the after profile showed initial deceleration at a greater rate between Trap 1 and Trap 2. Trucks, "after", entered slower on both approaches as did cars, "after", on the southbound approach. The implication is that the average driver was more aware of the crossing during phase II, even at the entry point, particularly on the southbound approach because of seeing the unactivated hardware.

Another observation that can be made from Figures 3 and 4, is the point that the motorist begins decelerating for the crossing. On the southbound approach, cars and trucks, before and after, all start their deceleration, albeit slight, at trap 4 or about 700 feet from the crossing. The implication is that this point is independent of both vehicle type and protection type. On the northbound approach (excluding the initial deceleration of "after" cars at the entry point) cars and trucks, before and after, all start their decelertion at Trap 5 or 6 or approximately 400 to 500 feet from the crossing.

Sanders concluded that (2, p. 508): "The resulting (speed) profiles showed that the crossing does not influence traffic behavior beyond 500 feet." This study does not support this conclusion. Lower entry speeds indicate some effect at more than 1000 feet and on the southbound approach, there is noticeable deceleration at 700 feet.

The grade crossings of Sanders' study were in urban or suburban environments. The northbound approach at the Goldsmith grade crossing, with numerous houses and businesses on the last mile, could be categorized as being suburban in nature whereas the southbound approach is strictly rural. The implication is that on high-speed, rural grade crossing approaches drivers take action further from the crossing.

Free-Flow Deceleration Rates

The mean deceleration rates, particularly for the free-flow categories, were of value only as an aid in analyzing trends in the speed profile. However, one driver characteristic can be noted. Drivers did not decelerate at a constant rate from point of intial action to desired slower speed at or near the crossing. A driver was more likely to decelerate early, maintain lower speed or accelerate again in some cases, then decelerate again closer to the crossing.

Sanders found that the point of maximum deceleration was generally about 45 feet from the crossing, indicating that drivers waited as long as possible before braking. (2) The data from the Goldsmith crossing study indicate maximum braking prior to Trap 7, greater than 200 feet from the crossing. This could be a significant difference between rural and suburban (or urban) grade crossings. It also indicates that drivers on a high speed rural approach will react early if alerted early.

Free-Flow Speed Distributions

In addition to analyzing mean speeds and mean speed profiles, the distribution of speeds was examined. First, this was done in order to determine if the pace speed had changed from phase I. Pace speed was only of interest as a break point to separate a subset of fastest drivers for analysis.

The pace speed remained constant before and after at 62-72 mph. The speed distribution curves were all similar and showed a slight shift toward slower speeds.

It is doubtful that any broad inferences can be drawn from the results of the above-pace speed analysis but some points are of interest. In regard to southbound vehicles, the mean speed profile of these groups is almost identical, but the percentage of cars entering 72 mph or greater after improvement was reduced from 23.6% to 13.6%. This reinforces the implication of greater or earlier awareness of the crossing in the after situation.

The northbound before and after groups had almost equal percentages enteringat 72 mph or greater, 17.4% vs. 17.2%, but the actual mean speed of this after group was significantly* lower in five of the eight traps.

Speed Comparisons with Signals Activated

In Phase II the improved crossing is always obstructed prior to arrival of a train after activation of the signal by the gate arm. Thus, there is no after group that was comparable to the first unobstructed group of phase I. The "first obstructed - before" (by train) group was compared to the "first obstructed - after" (by gate arm) group.

The mean speed profile values at the speed-trap locations for "first cars" are plotted in Figures 5 and 6. It can be seen in both figures that the first unobstructed group enters at approximately free-flow speed and decelerates rapidly, but not especially drastically, to between 25 to 40 mph, then appears to make the decision that it is safe to cross the tracks ahead of the approaching train. The result of a bad decision here will result in an accident statistic or a "near miss". Automatic gates take the option "to cross or not to cross" away from all drivers except those very close to the crossing. Taking the option away from the driver eliminates the

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* statistically significant

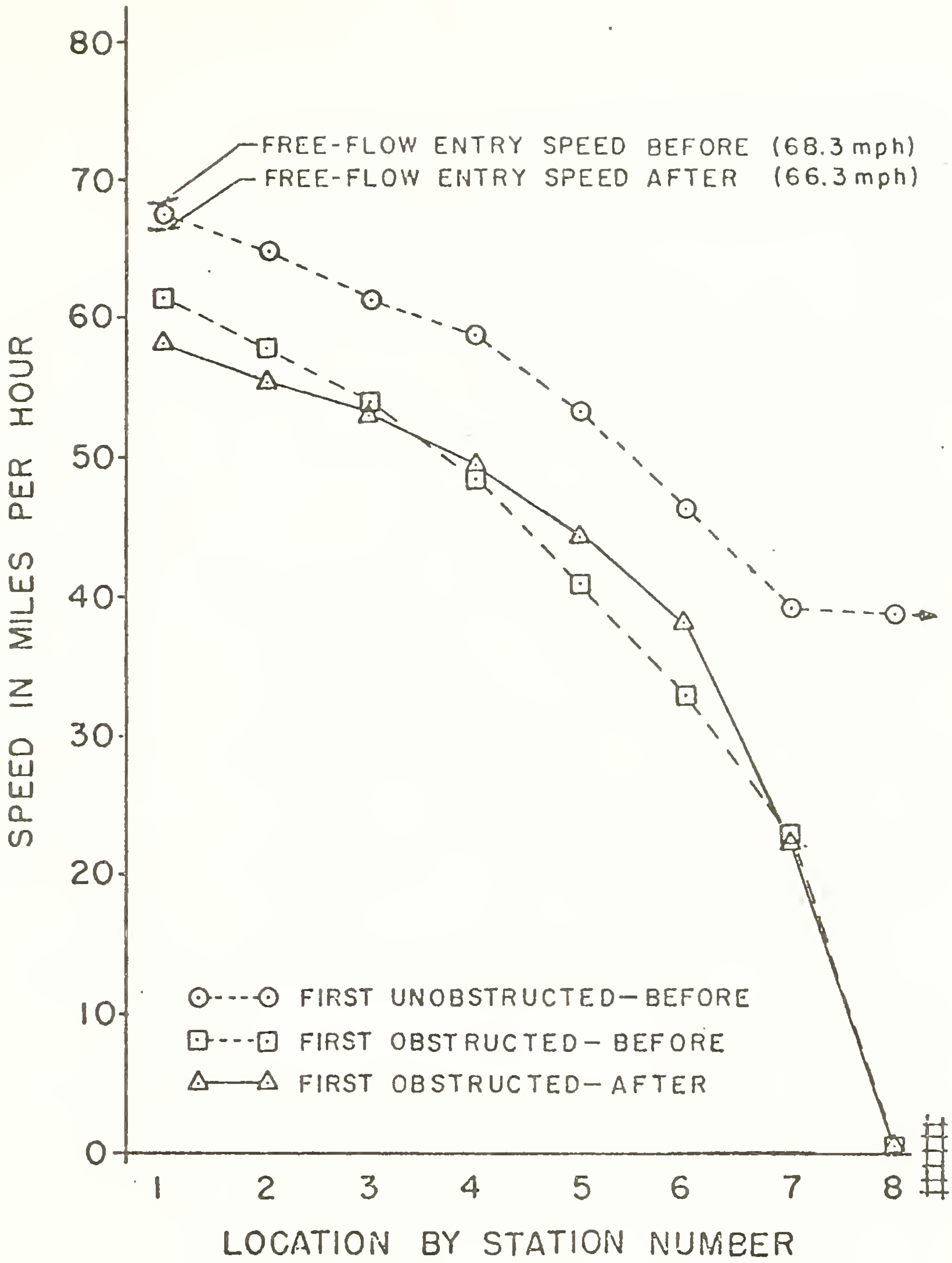

FIGURE 5 SPEED LOCATION GRAPH FOR VARIOUS CATEGORIES OF FIRST SOUTHBOUND CARS

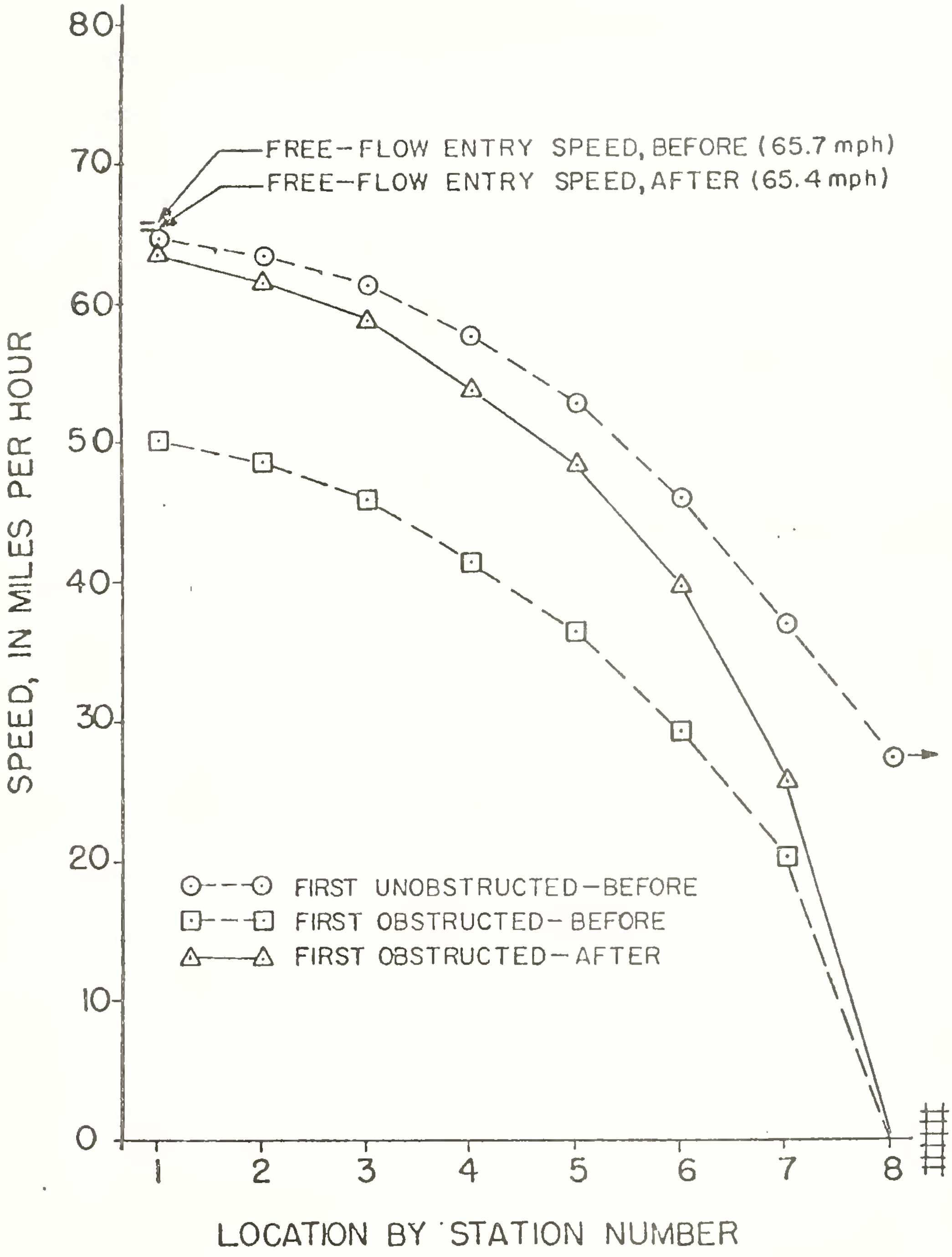

FIGURE 6 SPEED LOCATION GRAPH FOR VARIOUS CATEGORIES OF FIRST NORTHBOUND CARS

possibility of a bad decision and, therefore, this particular type of accident statistic.

There are differences in the northbound and southbound "first unobstructed - before" speed profiles. On the southbound approach, drivers slowed to about 40 mph at Trap 7, then appeared to make the decision to cross the tracks. Sight distance on this approach is unobstructed in both directions. On the northbound approach the profile followed practically the same speed pattern up to Trap 7. However, probably due to the restricted sight distance, the northbound, first unobstructed motorist continued to decelerate after Trap 7 to around 27 mph at Trap 8, delaying the decision to cross.

In regard to comparisons related specifically to the effect of the gates, the southbound approach will be considered first. Referring to Figure 5 it can be seen that the "first obstructed - after" (by gate) plots almost identically to the "first obstructed - before" (by train). The t-tests of the means show no significant difference between these two categories at any trap.* This would indicate that the gates were as effective a barrier to the motorist as a train across the highway or "very near" the crossing. Also, note that the two entry speeds are both significantly lower than free-flow car entry speed. The slower entry speeds indicate that on this approach with its unrestricted sight distance, the improved signal system appeared to have an affect on approaching drivers farther from the crossing than the first trap (>1162.5 feet).

On the northbound approach, it can be seen, by referring to Figure 6, that the "first obstructed - after" more closely follows the "first unobstructed - before". Even though the affect of gates

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* at 95% confidence level

(first obstructed - after) on the northbound approach does not appear to be as analogous to train presence (first obstructed - before) as it does on the southbound approach, a comparison of the group mean values of southbound and northbound "first obstructed - after", shows that from the 5th through 8th traps they are about the same. Other data indicate that free-flow vehicles on the northbound approach also appear to delay their reaction to the crossing until reaching the vicinity of Trap 5. The reasons for this may not be a function of protection type.

The relatively large difference of higher entry speeds of "first obstructed - after" vs. "first obstructed - before" does not necessarily negate the hypothesis that gates have a similar obstructing affect as a train across the road. Observation of the speed distribution of vehicles on the northbound approach showed that the lower "first obstructed - before" mean speeds were due to the existence of three unusually slow vehicles in a relatively small sample.

Following Vehicles

Data on following vehicles, northbound/southbound, before/after were also analyzed. The data show no meaningful differences due to the improved signal system in either direction of approach. The obvious conclusion is that following vehicles are primarily affected by other vehicles stopped ahead rather than by the system.

Fastest Vehicles After Signal Activation

Table 5 shows the percentage of cars of each sample which entered the before and after systems above 60 mph. The percentage reduction of these "high" speeds appears to be significant. The summary table shows

TABLE 5. SUMMARY OF FASTEST CARS, BEFORE AND AFTER, AS A PERCENT[1] OF THEIR TOTAL SAMPLE

NORTHBOUND

	SIGNALS ACTIVATED		FREE-FLOW	
	BEFORE	AFTER	BEFORE	AFTER
% > 60 MPH	26	42	50	68
% > 65 MPH	26	12	23	49
% > 72 MPH	12	12	18	16
% > 75 MPH	8	0	5	0
% > 80 MPH	2	0	2	0
% > 85 MPH	2	0	1	0

SOUTHBOUND

	SIGNALS ACTIVATED		FREE-FLOW	
	BEFORE	AFTER	BEFORE	AFTER
% > 60 MPH	19	31	92	75
% > 65 MPH	19	0	73	59
% > 72 MPH	7	0	26	14
% > 75 MPH	2	0	10	5
% > 80 MPH	2	0	3	3
% > 85 MPH	0	0	0	0

Note:

1. Percentage to nearest whole number

clearly that in all categories of both southbound and northbound cars, the percentage of high-speed cars shows reductions in all northbound cases $\geq$75 mph and all southbound cases $\geq$65 mph. The reduction in the percentage of cars traveling $\geq$65 mph was greater on the southbound approach than on the northbound approach for both conditions, "free-flow" and "signal activated". Possible reasons for this are as follows.

These speeds are at entry (1165 ft. from the crossing) and it has been previously noted that slowing down occurs farther from the track on the southbound approach than on the northbound approach.

An innovation was added to this particular automatic gate installation. Strobe lights, described previously, had been added to each gate arm. By constant observation during an entire summer and by conversations with visitors to the site, the strobe lights were probably the most impressive single feature of the new system. These high-intensity flashing lights were visible several thousand feet from the crossing. Even though a driver may not know what was ahead, he was alerted to the flashes.

Analysis of Deceleration Rates

From the data seven deceleration rates, one between each trap, were calculated for each of the observed vehicles by the equation previously derived. In phase I there were 3640 deceleration rates (520 vehicles x 7 locations between traps) which were placed into the classification 1 through 5 as previously mentioned. Only 20 deceleration rates from 13 vehicles were above classification 1, as shown in Table 6. In phase II there were 1827 deceleration rates with only nine being above classification 1, as shown in Table 7.

TABLE 6. SUMMARY OF HIGH DECELERATION RATES - BEFORE

Classification	Name	Number
2	undesirable	17
3	uncomfortable	2
4	very uncomfortable	1

Table is a summary of the high deceleration rates after the improvement.

TABLE 7. SUMMARY OF HIGH DECELERATION RATES - AFTER

Classification	Name	Number
2	undesirable	9
3	uncomfortable	0
4	very uncomfortable	0

CONCLUSIONS

1. Mean approach speeds, although a weak parameter for conclusions regarding warning effectiveness, did provide information on driver approach characteristics, that is;

They approached slower when the amount of stimuli present was greater, such as a train across the track or a gate down.

2. All free-flow plots and several statistical tests showed a consistent lowering of mean entry speeds 1100 feet from the crossing after improvement, implying that drivers were aware of the crossing after improvement farther from the crossing, due to the visibility of the gate arms in the raised position.

3. The plots of the "first obstructed - after" (by gates) were comparable to the "first obstructed - before" (by train), and in the case of southbound vehicles there was no statistical difference between values at any trap. Thus the gates with strobe lights had the same effect as a train across the road on slowing the average motorist.

4. The approach speeds of following vehicles were more affected by other vehicles than by the signal, before and after, and their approach speed profiles were independent of signal type.

5. Studying individual fastest cars entering the system just after signal activation showed that there was a substantial decrease in the percentages of speeds greater than 65 mph than when the signals were not activated, particularly on the southbound approach. The implication is that the signals, both before and after, had some impact at distances greater than Trap #1 (1162 feet).

6. There were no deceleration rates at the Goldsmith grade crossing that classified as emergency before or after upgrading the protection. There was a reduction in the decelerations above undesirable classifications for the after system but the numbers before as well as after were too few to permit statistical comparison.

7. Deceleration rates were a weak parameter for determining effectiveness of the new signals. Approach speeds appeared to give a good indication of effectiveness. Reduction of the percentage of fastest approaching vehicles appeared to be a very good indication of increased effectiveness.

List of References

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